Determining turbine and generator efficiency of a Pico hydro system at different flow rate

Hamza Ahmad Raza [1], Sara Sultan [1], and Kendra V. Sharp*[2].

[1.] *U.S. - Pakistan Center for Advanced Studies in Energy, National University of Science & Technology, Islamabad, 44000, Pakistan*

[2.] *School of Mechanical, Industrial & Manufacturing Engineering, 204 Rogers Hall, Oregon State University, Corvallis, OR 97331, USA*

***Abstract*—In this research, turbine and electric efficiency of a Pico hydro system was analyzed with installed impulse turbine and a 3 phase AC permanent magnet alternator. Other electrical components were also installed to handle the load variation. We investigated the effect of flow rate on turbine and generator efficiency. The results obtained from experiments revealed that the PMA power and shaft power are first increased with increasing water flow rate but start decreasing after a certain value of flow rate. The maximum PMA efficiency of 71.32 % was achieved at a flow rate of 19.1 gpm and afterwards it starts decreasing due to the stator and rotor losses inside the generator. The turbine efficiency was related to net and jet head and also water and jet velocity and was maximum at 19.7 gpm.**

***Index Terms*—AC Permanent alternator, Impulse turbine, Pelton turbine, Pico hydro power,**

I. INTRODUCTION

ENERGY is the convertible currency of technology without which the whole mankind could suffer for even the basic needs. The universe truly is dependent on energy in anyway and the demand is increasing due to the luxurious lifestyles and enhanced living standards. But the availability of resources is a question as most of the world's energy sector is utilizing fossils to generate power which is not only depleting the natural resources but also posing a threat to environment. [1]. At present, the world is already suffering from power shortfall. According to the Energy outlook report, 1.5 billion people have no access to electricity. Mostly, rural and hilly areas suffer from this situation due to lack of transmission networks [2]. Hence, there is an increased interest towards the sustainable and renewable sources of energy like solar, wind and hydro which are reliable and clean. Hydropower can be a viable solution in ecological as well as economical aspect especially when implemented at small scale. It contributes 19% in the world's electricity production. In the USA, hydropower provides electricity at 0.85 cents per kilo watt hour [3]. The trend of adaptation for hydro technology is increasing each year. According to International hydropower association data of 2014, global hydropower capacity has increased up-to 1000 GW from 302 GW in 1999 [4].

Large scale hydro technology is mature enough to obtain 80-90% system efficiency while a typical micro hydro system can yield 60-80% efficiency [5]. Large hydro power facilities are generally built with a huge reservoir and require a dam structure, connected with large grids, so there are high investment and capital costs. Further they are problematic for aquatic and marine life so they have a lot of social and environmental problems. But small hydro plants do not create a barrier to the passage of aquatic life, so they don't suffer from such problems [6]. Small hydro power is mostly 'run of river', so it doesn't require a dam structure, instead a small barrier called weir may be constructed to direct and control the water flow. The output power range for small hydropower is between 2.5 to 25 MW. There are further categories of small hydropower; Mini hydro (range < 2MW), Micro hydro (range < 500 kW), and Pico hydro (below 10 kW) [5][7].

The principle of hydropower lies in converting the gross head to mechanical and electrical energy, so the available power is directly proportional to flow rate of water and net hydraulic head [5][7].

$$P_0 = \rho g H Q$$

Where, P_0 is the hydraulic power measured in kW, ρ (kg/m^3) and g (m/s^2) are the water density and gravitational acceleration, respectively. The main components in small hydro power plants are intake, penstock, turbine and tailrace. If the storage system is used like in off grid connections, a battery bank and inverter is needed. The intakes are intended for screening the water stream from debris and other waste etc. to get the cleaner and air free water into the pipeline [8]. Water is taken from the source through intake and directed through penstock which heads it to the turbine with a certain pressure. The turbine under the influence of potential energy rotates the shaft which turns on the generator to produce power. The control valves are installed at the top of penstock to regulate the water flow through it [8][9].

II. Literature review

Our proposed system is based on a pico hydro flow system installed in Hydro & Climate lab by Bryan Cobb [10] at Oregon state university. He estimated the impulse turbine efficiency with a DC generator. Our objective is to build a system that could more efficiently produce electrical power over a range of flow rate by maintaining the frequency. As the AC load operates at 60 Hz frequency, below or above which it could be damaged. In a run of river pico hydro system, an increase in water flow rate results in increased rpm of the turbine shaft and generator. Hence generator produces current of more or less 60 Hz frequency. For this purpose, we installed some electric equipment to control the frequency and provide a safe range to the load. The generator we used is an AC Permanent Magnet Alternator with a rectifier kit. The AC output from generator is rectified to DC and provided to battery which stores the charge. An inverter is installed that takes the DC input from battery and converts it again to AC, according to our load requirement.

A Pico hydro system was proposed by Yadav & Chauhan [11] that was based on producing electricity by utilizing household water tank. The 6 V lead acid battery and inverter was used where inverter was capable of converting 6 V DC to 175 V AC. The power obtained from the system was of 8.408 W that was utilized to enlighten compact fluorescent lamp (CFL) of 5 W. The parameters such as maximum voltage, current and rpm provided were 5.646 V, 6.87 mA and 1500, respectively. An experiment was performed with different pipe diameters and revealed that such parameters were inversely related to it, whereas having direct relation with head [11].

Ridzuan et al. [12] investigated a power generation system from water flowing through the domestic pipes. He analyzed the output of generator with three cases, i.e. no load condition, with consumer load and with a battery charging system. He was able to produce 7 volts DC at water flow rate of 7 L/min. At no load condition when the battery was not attached, current rating was 90 mA and then it dropped to 10 mA after attaching battery as it started charging. This system was capable of producing 0.63 Watts electric powers. Lead acid 6V, 4.5Ah battery was used for the system [12].

H. Zainuddin [13] presented a system which uses domestic pipeline water energy to produce electricity. To find out pico hydro system operating time and maximum water flow, open circuit test was performed. Output voltage was 72 volts at 17 psi and 0.238 L/s between 1am to 4am when water usage was very low. An average open circuit voltage was 56-60 volts during a day. Maximum 1.2 W power was obtained at 13.8 volts and 371 rpm of generator. Ni-cd battery was used to assess the charging behavior. Battery charging was 5.98 volts and it charged up to 7.48 volts through 0.01 ampere and 14.37 volts. System actual efficiency at 11.96m head was 4.45% which was very low as compared to estimated 51 % efficiency [13].

Bryan Cobb [10] worked on a pico hydro system in Hydro and climate lab at Oregon state university. He measured the mechanical efficiency of the turbine and optimized the system taking into account input parameters like jet alignment, nozzle angle, and speed ratio.

III. Methodology

The experimental setup is based on a system used in [10] with some extra electrical equipment's added in it. The account of jet misalignment on turbine efficiency is not considered; however, the nozzle jet is aligned within center of turbine blades in this paper as shown in figure 1.

Figure 1: Nozzle alignment with turbine blades.

The equipment's used in this experiment are 3-phase permanent magnet alternator (PMA), pelton turbine, centrifugal pump, pressure transducer, flow rate sensor, laser tachometer, battery, rectifier, inverter, multi-meters, weighing display meter and loads. Their specifications are shown in table 1. The schematic and picture for experimental setup is shown in figure 2 below.

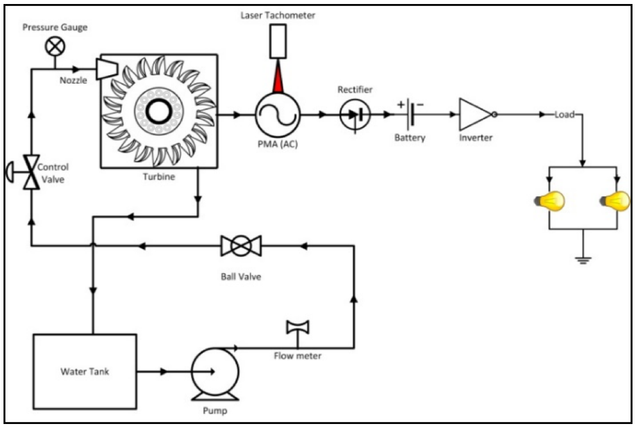


Figure 2 (a): Methodology Schematic

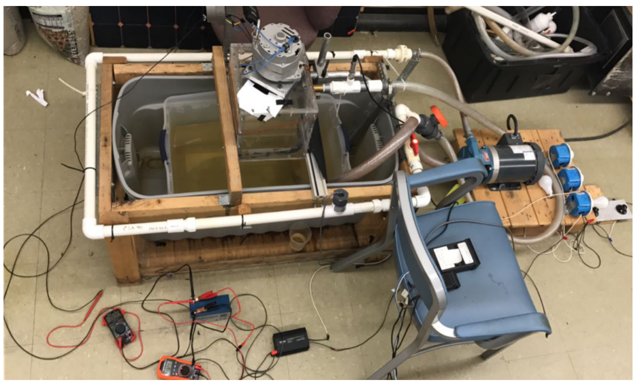


Figure2 (b): Experimental Setup

Table 1: Equipment details

Equipment	Specifications	Manufacturer
Permanent magnet alternator	Max rpm = 2700 Max 3-phase AC voltage = 170 V	Wind blue power [14]
Pelton turbine	Material = brass, PCD = 100 mm	ABS Alaskan[10]
Centrifugal pump	Power = 2 HP	MP Pumps
Pressure transducer	0 – 50 psig	Omega Engineering
Flow rate sensor	0 – 50 gpm	Omega Engineering
Laser tachometer	2.5 - 99,999 rpm	Neiko
Hanging Scale	0 – 50 kg	Mango spot LCD Electronics
Battery (dry lead acid)	Voltage = 12 V, Current = 9 Ah	
Rectifier	Max current = 150 A	Wind blue [15]
Inverter	Power = 300 W, Input voltage = 12 V, Current = (> 0.6 A)	SNAN [16]
Loads	2 bulbs (60 W each)	

The pelton turbine shaft is coupled with generator shaft by means of a coupler. The turbine rotation occurs due to water impingement on its blades and rpm is measured by laser tachometer. The setup comprises of water flow loop in order to get a controlled flow rate by means of a centrifugal pump and is measured through flow sensor with LED displaying meter.

A flow loop valve is used to cut off water supplied to pump whereas; flow rate is adjusted through flow control valve. The pressure transducer is installed just prior the nozzle exit and readings are displayed on a LED meter. Weighing display meter is also used to hold permanent magnet alternator (PMA) to measure force exerted on its rotor.

The three phase AC voltage is produced by PMA that is rectified to DC voltage with the aid of bridge rectifier. The rectifier selection is based on maximum current produced by PMA [17]. The rectifier used in this system is hung in a metal casing and capable of handling current up to 150 A [15]. The DC voltage produced by the rectifier is fed to the battery for charging. The DC voltage is converted to single phase AC voltage of 120 V by the inverter in order to turn on the load. The inverter needs greater than 0.6 A to make it operational with maximum resistance to input voltage 16 V and maximum power handling capacity of 300 W. The inverter accompanied functionality of low and overvoltage shutdown and operates normally at input voltage between 11-14 V [16].

IV. MATHEMATICAL CALCULATIONS

Turbine and generator efficiency determine the overall system's performance. Input volumetric water flow rate Q and head H are the key factors determining the turbine efficiency of a hydro system.

Some head losses occur in penstock and manifold which is why net head is not equal to gross head. Net head can be determined using jet head and both are related to nozzle's velocity coefficient as:

$$H_j = {C_v}^2 H_n \qquad (1)$$

The jet velocity can be calculated from the following equation using pipe velocity V_p:

$$V_j = \frac{A_1 V_1}{A_2} \qquad (2)$$

$$V_p = \frac{Q}{A_1} \qquad (3)$$

Using equations (1), (2), and (3), we can find the net head.

$$H_n = \frac{V_{j^2}}{2gC_{v^2}} \qquad (4)$$

The turbine shaft gets power from the water flowing through jet, placed at a specified head.

Turbine efficiency η_t is determined as:

$$\eta_t = \frac{w_s}{w_j} \qquad (5)$$

Where,

$w_s = shaft\ power$

$w_j = jet\ power$

Calculating the torque, using measured values of mass and shaft speed (see table 2), we can determine the shaft power of turbine.

$$w_s = 2\pi\omega\tau \qquad (6)$$

Where,

τ = torque produced in shaft

ω = shaft speed in radians per second

Jet power can be determined using flow rate and jet head.

$$w_j = \rho g Q H_j \qquad (7)$$

Where,

$\rho = Density\ of\ water$

$g = gravitational\ acceleration$

$Q = water\ flow\ rate$

The generator rotor gets mechanical power from turbine shaft and converts it into electrical power. Generator efficiency depends upon turbine's shaft power and electrical output power.

$$\eta_g = \frac{w_{elec}}{w_s} \qquad (8)$$

Where, the electric power from the generator is:

$$w_{elec} = VI \qquad (9)$$

VI = product of voltage and current across generator terminal.

V. Results & discussions

The battery voltage measured by a multi-meter was 12.51 V DC before running a system. Initially, system behavior was observed at no load condition (without battery) to check maximum voltage a PMA can produce. At the flow rate of 22 gpm, PMA was capable of generating 170 V AC. Further experiments were performed by connecting battery with rectifier output and inverter. The output voltage from inverter is 110 V AC. Its input voltage and output current with the other parameters are shown in table 2 below.

Table 2: Readings measured with battery connected after rectifier

Flow rate	Pressure	PMA speed	Output Current	PMA Power	Turbine efficiency	Generator efficiency	System efficiency
(gpm)	(Psi)	(rpm)	amps)	(Watt)	%	%	%
9.4	5.86	350	0.04	4.4	27.92	38.54	10.76
11.2	8.7	400	0.099	10.89	28.29	55.65	15.74
12.3	10.2	450	0.15	16.5	29.94	59.95	17.95
15.4	16.29	559	0.3	33	30.31	60.33	18.29
17.4	20.88	624	0.5	55	32.35	65.51	21.19
19.1	25.26	766	0.81	89.1	36.37	71.32	25.94
19.7	28.4	860	0.96	105.6	41.99	66.93	28.11
22	32.09	920	1.149	126.39	37.05	64.80	24.01

The PMA power, pressure and torque exerted on PMA shaft totally depend on water flow rate and increase with increasing flow rate.

A. Turbine Efficiency

In order to calculate the turbine efficiency, the shaft power is determined from equation (6). The ratio optimization between shaft power and jet power is important for the turbine efficiency. Jet power was calculated using jet head and flow rate and was the same as obtained by Cobb [10]. As the turbine efficiency is greatly influenced by water flow rate, the effect is studied at different flow rates to find the maximum efficiency for this system (as shown in figure 3). At a flow rate of 19.7 gpm, the maximum turbine efficiency of 41.99 % is achieved. We expected the results to be comparable with Cobb's experimental results but the turbine efficiency achieved from our experiment is lower as obtained by Cobb. This is due to the difference in shaft power. We performed experiment with a direct load system as done by Bryan Cobb, the range of turbine rpm obtained was more or less same as that of Cobb's experimental results. But when the battery was installed, the load was increased and we obtained lower rpm values. Consequently shaft power was decreased. Thus we couldn't obtain the maximum shaft power even at the highest flow rate.

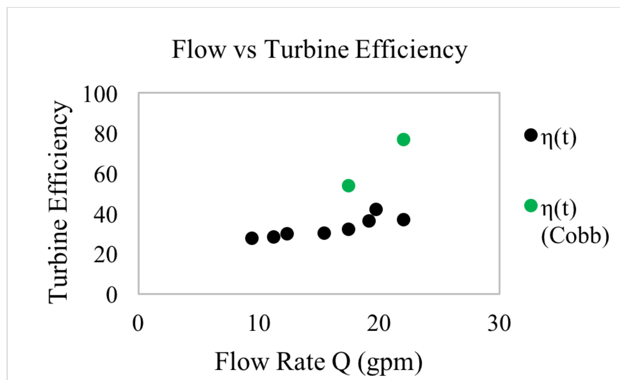


Figure 3: Flow rate versus turbine efficiency

Figure 3 shows that turbine efficiency increases as we increase the flow rate, because jet power is being increased. The value is maximum at 19.7 gpm and beyond this value, the efficiency starts decreasing. This might be because of losses occurred inside blades, which makes water stream velocity less when leaving through blades. In ideal case, the water exit angle during leaving blades is 180˚ which means full water jet force is utilized for the turbine rotation [18][19]. So it means that there is lower water exit angle obtained from blades in this experimental setup and also a different coupler is used for turbine and PMA shaft coupling whose weight is different from the previous one, thus leading to lower shaft power value and consequently achieving less turbine efficiency.

B. Generator Efficiency

The maximum PMA efficiency obtained is 71.32 %. We expected it to be at least 80 %. Cobb calculated it as 84% with a direct load system and DC generator. But in our case, we are using battery bank system which includes conversion losses. This system uses a rectifier that converts AC output from generator to DC and then a rectifier converts the DC output from battery to again AC. This decreases the overall efficiency.

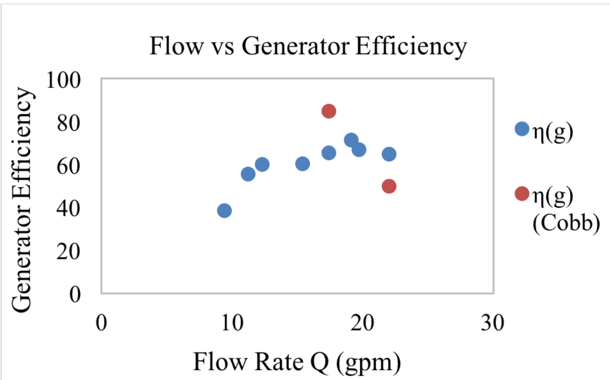


Figure 4: Flow rate versus generator efficiency

The maximum PMA efficiency of 71.32 % is achieved at flow rate of 19.1 gpm and after that it starts decreasing (see fig.5.). This behavior is because of losses occurred inside PMA such as stator and rotor losses. Similar behavior has been observed in other experiments in literature [20][21]. The stator losses are further categorized as copper and iron loss. Copper losses are due to current induced from armature winding also termed as I^2R loss and is temperature dependent. So as flow rate increases, the more current is passed into winding that results in increasing copper temperature and leads to a poor PMA efficiency. The iron loss is due to magnetizing material placed in a varying magnetic field and is linked with hysteresis and eddy current loss that affects PMA efficiency. In an experiment, the readings are recorded by varying flow rate at some time interval, thus results in causing varying magnetic field that disturbs some of position of magnetic domains within a magnetic material. An extra energy is consumed in terms of hysteresis loss to work against such domain mislay [20]. The rotor eddy current loss is also due to uncontrolled rectifiers [21] used in this project. There are also some other conductive parts of a PMA that results in induced electromotive force and current in them, thus dissipate as heat in terms of eddy current loss. Such induced body current does not take part in output power and leads to lower PMA efficiency [20].

C. Pipe and jet velocity

The pipe velocity 'V_p' in a flow loop pipe and jet velocity 'Vj' at nozzle exit are calculated at different flow rates from equation (3) and (2), respectively. The maximum pipe and jet velocity is achieved at maximum flow rate which is 5.16 ft/s and 90.6 ft/s as shown in figure 5.

The net and jet head are calculated from equation (4) and (1), respectively. The net and jet head obtained for such system is within range of 24.37 – 134.1 ft and 23.17 – 127.46 ft. The jet power lies between 30.25 (41) – 390.14 (528.9) lbf ft/s (W) determined by using equation (7) at different flow rates. It is observed from calculated results that water and jet velocity, net and jet head are highly dependent on flow rate.

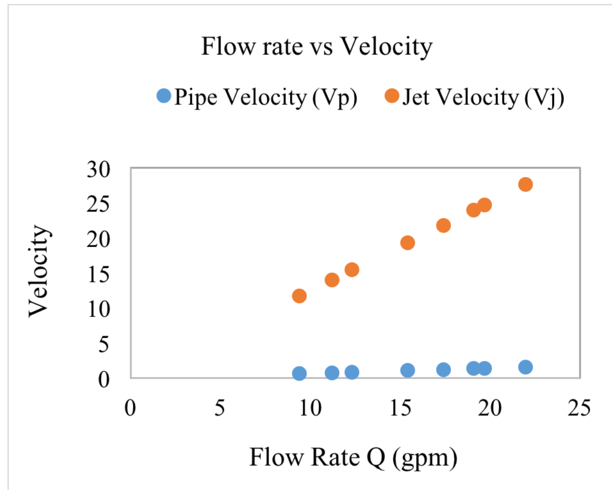


Figure 5: Water and jet velocity obtained at different flow rates

Bryan Cobb directly connected the load with DC output of generator and measured the electrical efficiency of the system because his research was focused on mechanical system of this experiment. Our objective was to control the frequency of electrical system in order to provide safe range of frequency to the load and measure the system efficiency with this scenario. To achieve our objectives, we installed a battery which could take the rectified DC output to store charge and forward it to the inverter for AC conversion. This was the reason of efficiency drop in our case.

VI. CONCLUSION

AC generator in a pico hydro system demands to attach a battery at its output before connecting the load. The generator frequency increases or decreases with variation in flow rate of water that fluctuation disturbs the load. Turbine and generator efficiencies were estimated and compared with Bryan Cobb's experimental results. He tested the efficiency of turbine with a direct load connection, taking into account different parameters like speed ratio, jet misalignment and nozzle angle.

In our system, we attached a battery-inverter circuit to control the frequency. That system was able to provide the safe frequency according to load requirement but the system efficiency was decreased.

Appendix

1) Pico Hydro System Specifications

Water Density	1000 kg/m^3 (1.94 slug/ft^3)
Gravity	9.8 m/s^2 (32.2 ft/s^2)
Nozzle Diameter	0.375 inch (0.02625 ft)
Pipe Diameter	1.31 inch (0.11 ft)
Moment arm of PMA	0.27 ft

2) Input Variables

Variable	Reading 1	Reading 2
Flow rate (Q)	19.1 gpm (0.0343 ft3/s)	22 gpm (0.0490ft3/s)
Pressure (P)	25.26 psi (2345lbf/ft2)	32.09 psi (4620.96lbf/ft2)
Net Head (H)	101.65 ft	134.1ft
Jet Head	95.8 ft	127.46ft

3) Dependent Variables

Variable	Reading 1	Reading 2
Velocity (v)	38.63 ft/s	90.60 ft/s
Force (F)	19.6 lbf	25.48lbf
Torque (T)	1.568 ft-lbf	2.03 ft-lbf
Shaft speed (rpm)	766	920
Voltage (V)	110 volts	110 volts
Current (I)	0.96 amps	1.149 amps

4) Power (ft-lb$_f$/s)

Variable	Reading 1	Reading 2
Jet Power (Input)	253.10 Watt	387.88
Shaft Power (Output)	92.06	143.74
Electric Power (Output)	65.66	93.14

5) Efficiency (%)

Turbine Efficiency	36.37 %	37.05 %
Generator Efficiency	71.32 %	64.80 %
Overall Efficiency	25.9 %	24 %

Acknowledgment

We are thankful to Dr. Kendra Sharp for her tremendous support and guidance throughout the project. The sponsorship of USAID and NUST is acknowledged.

References

[1] I. Dincer, “Renewable energy and sustainable development: a crucial review,” *Renew. Sustain. Energy Rev.*, vol. 4, no. 2, pp. 157–175, 2000.

[2] A. Development Bank, “Energy Outlook for Asia and the Pacific,” 2009.

[3] U. K. Mirza, N. Ahmad, T. Majeed, and K. Harijan, “Hydropower use in Pakistan: Past, present and future,” *Renew. Sustain. Energy Rev.*, vol. 12, no. 6, pp. 1641–1651, 2008.

[4] “Blog | International Hydropower Association.” [Online]. Available: https://www.hydropower.org/blog/hydropower-generation-and-potential-around-the-world.

[5] O. Paish, “Small hydro power: Technology and current status,” *Renew. Sustain. Energy Rev.*, vol. 6, no. 6, pp. 537–556, 2002.

[6] A. A. Williams and R. Simpson, “Pico hydro - Reducing technical risks for rural electrification,” *Renew. Energy*, vol. 34, no. 8, pp. 1986–1991, 2009.

[7] D. K. Okot, “Review of small hydropower technology,” *Renewable and Sustainable Energy Reviews*, vol. 26. pp. 515–520, 2013.

[8] P. I. Cunningham, Woofenden, “Microhydro-Electric Systems Simplified | Home Power Magazine,” *Home power magazine*, 2007. [Online]. Available: http://www.homepower.com/articles/microhydro-power/equipment-products/microhydro-electric-systems-simplified.

[9] S. Mishra, S. K. Singal, and D. K. Khatod, “Optimal installation of small hydropower plant—A review,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 8, pp. 3862–3869, 2011.

[10] B. R. Cobb and K. V. Sharp, “Cobb & Sharp_Impulse (Turgo and Pelton) turbine performance characteristics impact on pico-hydro installations_Elsevier_2012,” *Renew. Energy*, vol. 50, pp. 959–964, 2013.

[11] G. Yadav and a K. Chauhan, “Design and Development of Pico Micro Hydro System By Using House Hold Water Supply,” pp. 114–119, 2014.

[12] M. J. M. Ridzuan, Z. Zarina, K. Azduwin, S. M. Hafis, and K. M. Firdaus, “Development of Pico-Hydro Turbine for Domestic Use,” in *Advanced Research in Materials and Engineering Applications*, 2015, vol. 695, pp. 408–412.

[13] Z. Zainuddin, H and Khamis, A and Yahaya, MS and Basar, MFM and Lazi, JM and Ibrahim, “Investigation on the performance of pico-hydro generation system using consuming water distributed to houses,” *Dev. Renew. Energy Technol. (ICDRET), 2009 1st Int. Conf.*, vol. 11262478 I, pp. 1–4, 2009.

[14] “worlds most powerful PMA/PMG’s.” .

[15] “External Rectifier Connection Kit.” .

[16] “300 WATT PURE SINE WAVE INVERTER OWNER ’ S MANUAL.”

[17] M. Little, “Wind Turbine Rectifier Design Guide,” no. May, pp. 1–11, 2008.

[18] “Pelton Turbine - Working & Design Aspects ~ Learn Engineering.” .

[19] D. Apsley, “T4: Pumps and Turbines,” vol. 1, no. 1, pp. 1–19, 2013.

[20] C. Huynh, L. Zheng, and D. Acharya, “Losses in High Speed Permanent Magnet Machines Used in Microturbine Applications,” *J. Eng. Gas Turbines*

Power, vol. 131, no. 2, p. 22301, 2009.

[21] A. A. Qazalbash, S. M. Sharkh, N. T. Irenji, R. G. Wills, and M. A. Abusara, "Rotor Eddy Current Power Loss in Permanent Magnet Synchronous Generators Feeding Uncontrolled Rectifier Loads," *IEEE Trans. Magn.*, vol. 50, no. 6, 2014.

2. Primary Training Activities

- **Course Catalogue**

No.	Course title	Course number	Course instructor
1	ST/BASIC MATLAB FOR ENV SCIENCE	CE_640_X003_F2016	Dr. David Hill

- **Seminars**

No.	Seminar title	Speaker	Outcomes
1	Transformation and global technology in design. 09/23/2016	Dr. Winter(MIT)	The speaker investigated the technical and market constraints for different designs. The problem was with price and performance mismatch and Dr. Winter's designs controlled it observing the principle of reverse innovation i.e. adding or removing features could alter cost and performance accordingly.
2	Developing a research plan. 10/08/2016	Dr. Bryony Dupont (OSU)	She told how to plan our research and formulate a good abstract. She highlighted the techniques for effective reading of the research articles.
3	Communicating Your Work. 10/15/2016	Dr. Bryony Dupont (OSU)	She delivered the skills to present research work effectively in the form of posters and oral presentations.
4	Best practices in writing 11/05/2016	Dr. Bryony Dupont (OSU)	The seminar was about writing good research articles. She delivered some important tips to make a good impact on writing skills.
5	Using information and Communication Technology (ICT) to improve Healthcare in Pakistan 10/27/2016	Mustafa Naseem	Mustafa Naseem is a technologist and social entrepreneur who has been working for immunization tracking system to increase the vaccine coverage for polio control in Punjab, Pakistan. He developed an android app featured to track the workers, monitor the performances and digital data recording of victims and their guardians. The best thing about this app was its flexibility, i.e. it is easy to use even for illiterate people and includes Urdu language option.
6	Symbiotic System for Energy, Water, and Food 10/21/2016	Dr. Alexander H. Slocum (MIT)	The focus of talk was to identify the need of the world to switch towards the renewables and promote the strategies to interlink all three basic essentials of mankind, i.e. energy, water and food. He discussed the perspectives of different innovative researches going on in the world regarding solutions to contribute towards improvement of living standards by proposing efficient and low cost designs.

- **Field Trips**

No.	Location	Time	Learning
1	Wave Lab Tour, OH Hinsdale wave Research Laboratory 3550 S.W Jefferson Way, Corvallis.	09-15-2016 01 pm	We observed different wave-structure interactions and studied wave hydrodynamics and its effects on structures. We learnt generating high pressure waves of high frequencies and large wavelengths and waves with similar characteristics to that of Tsunami waves and studied the influence of multidirectional waves with varied pressure and wavelengths on rigid structures.

- **Workshops Attended**

No.	Title	Venue	Learning
1	Thesis/Dissertation Literature Review Workshop	Autzen Classroom, Valley Library, OSU, Corvallis Oct, 04, 2016,	The objective was to learn about managing and using resources effectively for research. Got information about the available resources to find literature like web of science and google scholar and explored new databases.
2	Showing Your Research with Impact Metrics	Autzen Classroom, Valley Library, OSU, Corvallis Oct, 13, 2016	The purpose was to find the appropriate journals and increase the worth of research. We learnt quantitative measures for scholarly impact (e.g., citations, impact factor, Eigen factor, and h-index), open access initiatives (OA), and their correlations.
3	Introduction to LaTeX	Willamete West Classroom, Valley Library, OSU Oct, 18, 2016,	Learnt to use ShareLatex.com to create projects, importing figures and writing equations in LaTeX and created files with different extensions like .tex for text file. Also applied different commands in the example project. Used bibtex citation for bibliography in .bib file.
4	Basic Endnote learning Workshop	Autzen Classroom, Valley Library, OSU, Corvallis Oct, 06, 2016,	Explored basic endnote features and learnt about formatting bibliographies' with its powerful management tools. Learnt creating customized endnote library and organizing and importing citations and pdfs and annotating attached pdfs.
5	Advanced Endnote learning Workshop	Autzen Classroom, Valley Library, OSU, Corvallis Oct, 06, 2016,	Learnt more advanced features like managing and importing pdf files with references, retrieving full text articles using built-in endnote tools, exporting references from various databases, customizing citations and styles and modifying to create new styles, and creating backup by compressing libraries in zip files.
6	Graduate publishing tips	Autzen Classroom, Valley Library, OSU, Corvallis Oct, 24, 2016,	Objective was to learn some key publishing strategies and tips to get our writings published. Learnt how to include and discuss the results and methodology. Hands on practice to critically evaluate different literature works.

3. Cultural Exchange Highlights

- **Cultural Excursions**

No.	Excursion	Outcomes	Comments
1	Portland	-Helpful in enhancing the communication skills -Explored the culture and interact with people -Learnt about facilities in Oregon	-Explored submarine and space technologies. -Visited OMSI and had exposure to USS Blueback Navy submarine and space science and planetarium
2	New Port	Visited Oregon's second old and tallest Yaquina head light house in Newport (National register landmark built in 1872-73)	Ripley's museum had some unbelievable things like lighthouse man, human unicorn, doubled eye man, human floor lamp etc.

- **Etihad Cultural Event**

Etihad cultural event was organized by Saifi at Alexander field house and it was a fun sports event. We enjoyed playing badminton and met with other students from different countries.

- **American Football Match**

We had a chance to watch a thrilling match Beavers vs Arizona State at Reser stadium. It was a treat to watch the winning moments and excited crowd. We met a lot of new people there.

- **USA Election**

To follow American elections sitting in US would be memorable. It was a nice experience to know about US electoral system.

- **Toastmaster Speech Craft**

It was the most helpful and learning session. It enhanced my communication and presentation skills. We learnt how to be confident and how to speak on the toe without preparing like in table topics.

- **Halloween**

Attending the Halloween with local culture was a great fun. We celebrated the event 'Haunted House' in MU where people were in different scary costumes.

- **Thanksgiving**

It was a nice event. Had dinner with our coordinator Tabeel in Al-Jebel restaurant.

- **Hike to Water falls**

We had an amazing hike opportunity with Meredith, our lab mate. She made our day. We had gone through 7 different water falls throughout the hike and it was fantastic view.

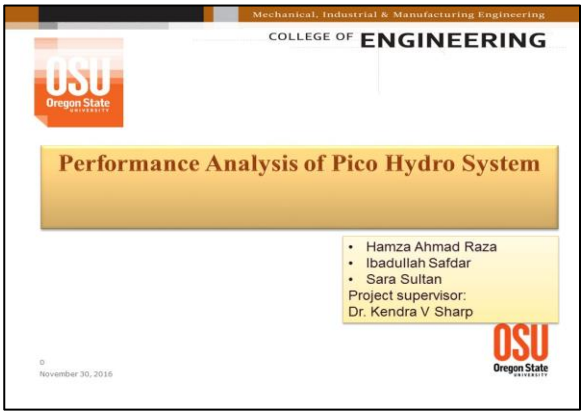
- **Pakistan Student Association**

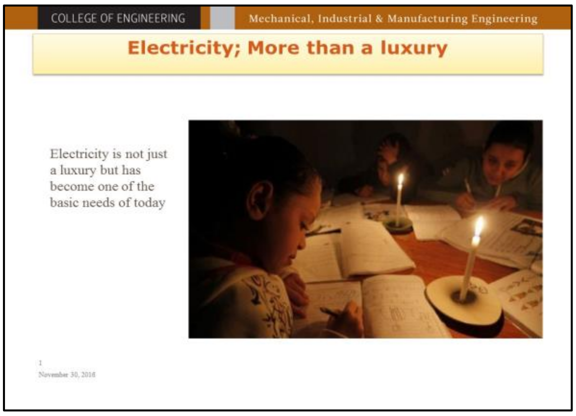
Met different Pakistani students studying in Oregon. Had a special Eid dinner with them. It was a good opportunity to have them all on same platform and getting guidance from their experiences.

- **Salman Al-Farsi Mosque**

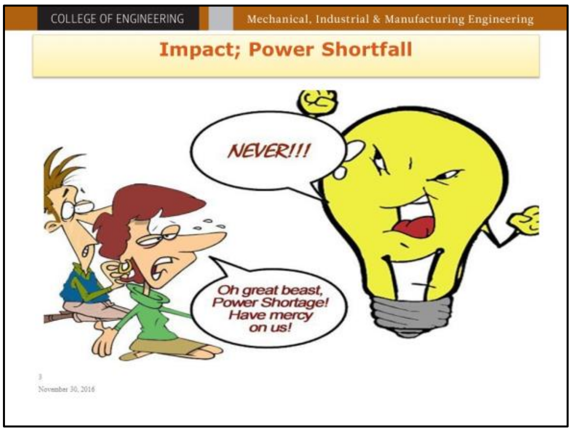
It was nice to find a mosque nearby and we all went to mosque each Friday at 1 pm to say prayer. We met a lot of Muslims and found a Pakistani 'Uncle Saeed' who was so kind to us and helped make our stay enjoyable.

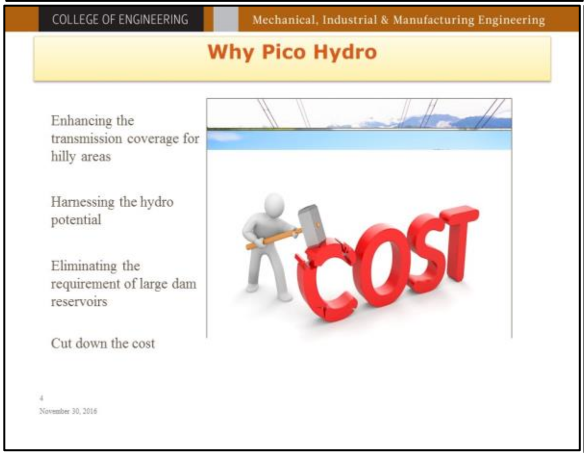
Appendix A

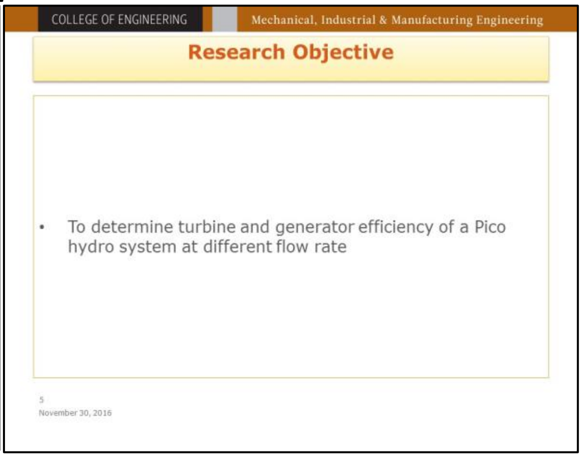

Mechanical, Industrial & Manufacturing Engineering
COLLEGE OF ENGINEERING
OSU
Oregon State
Performance Analysis of Pico Hydro System
• Hamza Ahmad Raza
• Ibadullah Safdar
• Sara Sultan
Project supervisor:
Dr. Kendra V Sharp
November 30, 2016


COLLEGE OF ENGINEERING
Mechanical, Industrial & Manufacturing Engineering
Electricity; More than a luxury
Electricity is not just a luxury but has become one of the basic needs of today
November 30, 2016


COLLEGE OF ENGINEERING
Mechanical, Industrial & Manufacturing Engineering
Challenges
• Supply-demand problem. (More demand less supply)
• Fossils depletion; Consuming oil like food
• Environmental concerns; Health disasters
November 30, 2016

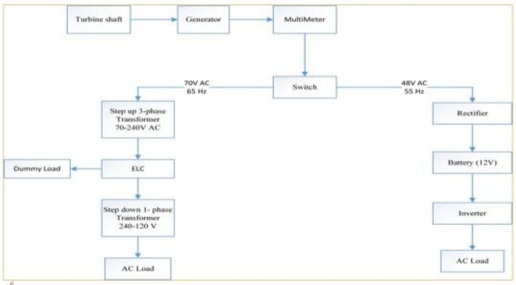

COLLEGE OF ENGINEERING
Mechanical, Industrial & Manufacturing Engineering
Impact; Power Shortfall
NEVER!!!
Oh great beast, Power Shortage! Have mercy on us!
November 30, 2016


COLLEGE OF ENGINEERING
Mechanical, Industrial & Manufacturing Engineering
Why Pico Hydro
Enhancing the transmission coverage for hilly areas
Harnessing the hydro potential
Eliminating the requirement of large dam reservoirs
Cut down the cost
COST
November 30, 2016


COLLEGE OF ENGINEERING
Mechanical, Industrial & Manufacturing Engineering
Research Objective
• To determine turbine and generator efficiency of a Pico hydro system at different flow rate
November 30, 2016

COLLEGE OF ENGINEERING | Mechanical, Industrial & Manufacturing Engineering

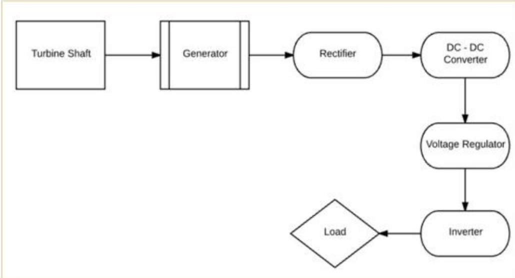
Proposed solutions
Case 1: ELC based system



6
November 30, 2016

COLLEGE OF ENGINEERING | Mechanical, Industrial & Manufacturing Engineering

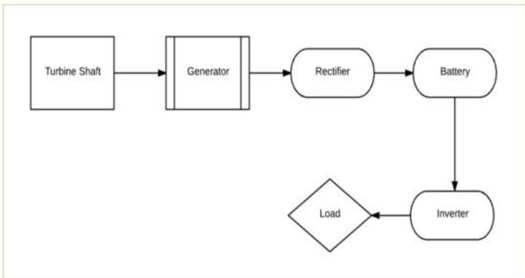
Case 2: Installation of DC-DC converters and inverter



7
November 30, 2016

COLLEGE OF ENGINEERING | Mechanical, Industrial & Manufacturing Engineering

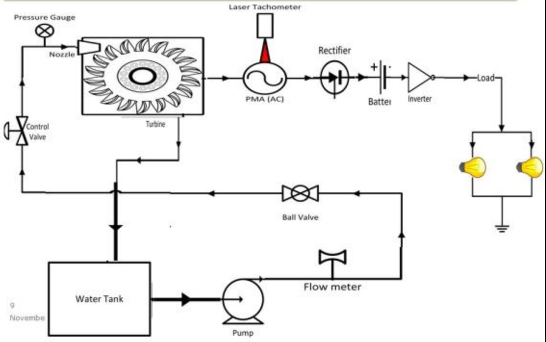
Case 3: Battery charging system



8
November 30, 2016

COLLEGE OF ENGINEERING | Mechanical, Industrial & Manufacturing Engineering

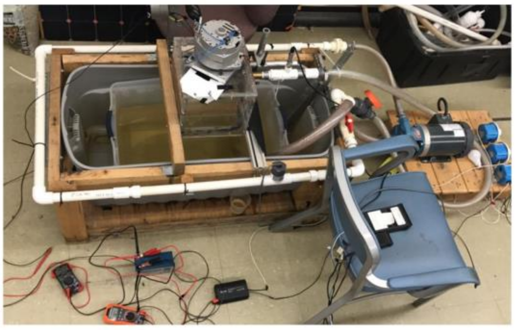
Methodology



9
Novembe

COLLEGE OF ENGINEERING | Mechanical, Industrial & Manufacturing Engineering

Experimental setup



COLLEGE OF ENGINEERING | Mechanical, Industrial & Manufacturing Engineering

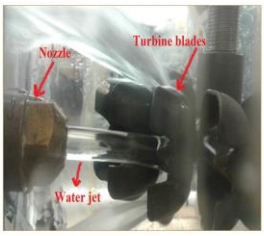
Concerns

- Generator was out of order
- Shaft and rotor adapter size
- Laser-tachometer issues
- Water leakage

11
November 30, 2016

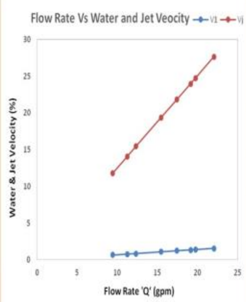
Nozzle Adjustment

- The nozzle jet is aligned within centre of turbine blades.
- Water stream exit angle.
- To achieve better turbine efficiency.

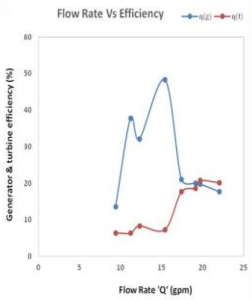


Results and discussion

- The maximum water velocity is 5.16 ft/s.
- Maximum nozzle jet velocity achieved is 90.6 ft/s.
- Water velocity in a flow loop and jet velocity at nozzle exit are totally dependent on flow rate.



- The maximum generator efficiency achieved is 48.35 %.
- Turbine efficiency decreases at high flow rates.
- Turbine efficiency increases as flow rate increases.
- Maximum turbine efficiency achieved is 20.75.



- The net and jet head obtained for such system is within range of 7.43 – 40.9 m and 7.1 – 38.8 ft.
- The system hydraulic power calculated at maximum flow rate is 556.5 W.

Conclusion

- At more flow rate, PMA efficiency decreases.
- Turbine efficiency increases with an increase in flow rate.
- The power obtained from PMA in this system is sufficient to charge a 12V DC battery.
- The load can be operated for about 1.6 hrs.

Calculating historic (1950 - 2000) average precipitation and temperature for Pakistan

- A historic gridded precipitation and temperature data within range of 1950 – 2000 has been generated by using Mosier downscaling package for Pakistan.
- **Input file for precipitation:**

1. 30 arc second resolution based precipitation data from WOrldCLim.
2. 0.5° precipitation gridded data obtained from Global Precipitation Climatology Centre (GPCC).

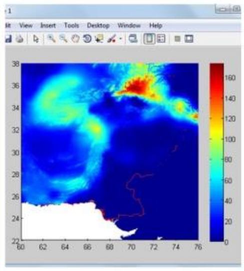
- **Input files for temperature**

1. 30 arc second resolution based temperature data from WOrldCLim.
2. mean temperature obtained from Climate Research Unit (CRU).

- **Outputs**

1. The downscaled gridded data of precipitation and temperature in ASCII format are obtained by using Mosier tool.

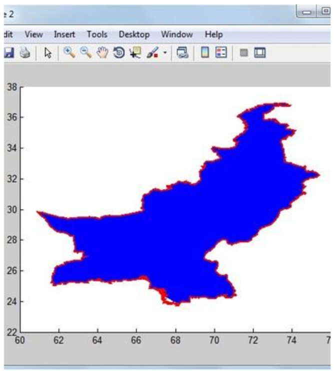
- ASCII files are read in Matlab.



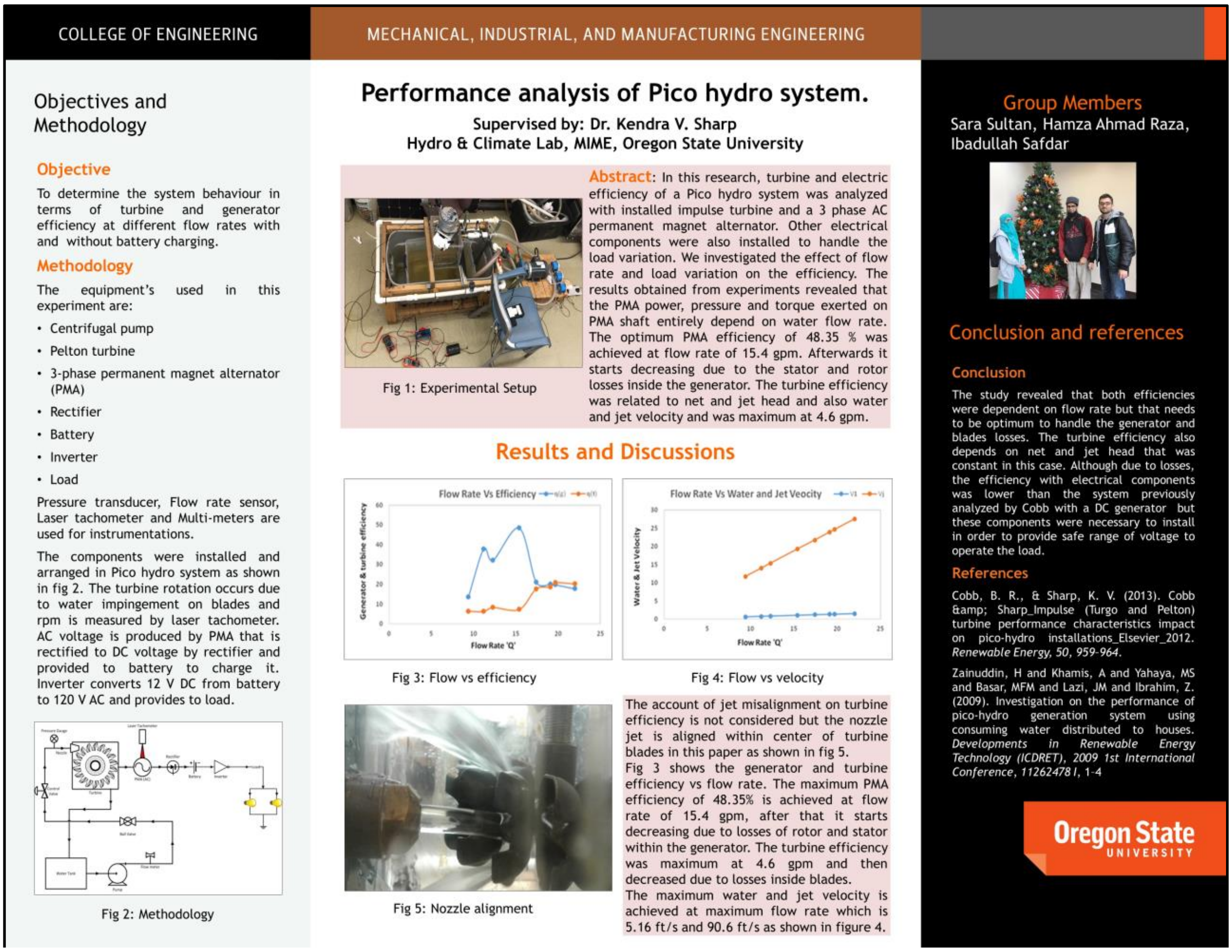
- **Boundary creation**

1. Shape files are read in matlab.

- A program is written to obtain total average precipitation and temperature within a specified boundary.



Appendix B


COLLEGE OF ENGINEERING
MECHANICAL, INDUSTRIAL, AND MANUFACTURING ENGINEERING
Objectives and Methodology
Objective
To determine the system behaviour in terms of turbine and generator efficiency at different flow rates with and without battery charging.
Methodology
The equipment's used in this experiment are:
• Centrifugal pump
• Pelton turbine
• 3-phase permanent magnet alternator (PMA)
• Rectifier
• Battery
• Inverter
• Load
Pressure transducer, Flow rate sensor, Laser tachometer and Multi-meters are used for instrumentations.
The components were installed and arranged in Pico hydro system as shown in fig 2. The turbine rotation occurs due to water impingement on blades and rpm is measured by laser tachometer. AC voltage is produced by PMA that is rectified to DC voltage by rectifier and provided to battery to charge it. Inverter converts 12 V DC from battery to 120 V AC and provides to load.
Fig 2: Methodology
Performance analysis of Pico hydro system.
Supervised by: Dr. Kendra V. Sharp
Hydro & Climate Lab, MIME, Oregon State University
Abstract: In this research, turbine and electric efficiency of a Pico hydro system was analyzed with installed impulse turbine and a 3 phase AC permanent magnet alternator. Other electrical components were also installed to handle the load variation. We investigated the effect of flow rate and load variation on the efficiency. The results obtained from experiments revealed that the PMA power, pressure and torque exerted on PMA shaft entirely depend on water flow rate. The optimum PMA efficiency of 48.35 % was achieved at flow rate of 15.4 gpm. Afterwards it starts decreasing due to the stator and rotor losses inside the generator. The turbine efficiency was related to net and jet head and also water and jet velocity and was maximum at 4.6 gpm.
Fig 1: Experimental Setup
Results and Discussions
Flow Rate Vs Efficiency
Generator & turbine efficiency
Flow Rate 'Q'
Fig 3: Flow vs efficiency
Flow Rate Vs Water and Jet Veocity
Water & Jet Velocity
Flow Rate 'Q'
Fig 4: Flow vs velocity
Fig 5: Nozzle alignment
The account of jet misalignment on turbine efficiency is not considered but the nozzle jet is aligned within center of turbine blades in this paper as shown in fig 5.
Fig 3 shows the generator and turbine efficiency vs flow rate. The maximum PMA efficiency of 48.35% is achieved at flow rate of 15.4 gpm, after that it starts decreasing due to losses of rotor and stator within the generator. The turbine efficiency was maximum at 4.6 gpm and then decreased due to losses inside blades.
The maximum water and jet velocity is achieved at maximum flow rate which is 5.16 ft/s and 90.6 ft/s as shown in figure 4.
Group Members
Sara Sultan, Hamza Ahmad Raza, Ibadullah Safdar
Conclusion and references
Conclusion
The study revealed that both efficiencies were dependent on flow rate but that needs to be optimum to handle the generator and blades losses. The turbine efficiency also depends on net and jet head that was constant in this case. Although due to losses, the efficiency with electrical components was lower than the system previously analyzed by Cobb with a DC generator but these components were necessary to install in order to provide safe range of voltage to operate the load.
References
Cobb, B. R., & Sharp, K. V. (2013). Cobb & Sharp_Impulse (Turgo and Pelton) turbine performance characteristics impact on pico-hydro installations_Elsevier_2012. Renewable Energy, 50, 959-964.
Zainuddin, H and Khamis, A and Yahaya, MS and Basar, MFM and Lazi, JM and Ibrahim, Z. (2009). Investigation on the performance of pico-hydro generation system using consuming water distributed to houses. Developments in Renewable Energy Technology (ICDRET), 2009 1st International Conference, 11262478 I, 1-4
Oregon State UNIVERSITY

Appendix C

- **Course Catalogue**

No.	Course title	Course number	Course instructor
1	ST/BASIC MATLAB FOR ENV SCIENCE	CE_640_X003_F2016	Dr. David Hill

Appendix D

```
%Sara Sultan
%MATLAB Assignments


%Assignment 1

clear all
clf

%Part 4a

r=[1 2 8 20];
c=2*pi*r;
A=pi*r.^2;

figure(1)
subplot(211)
plot(r,c,'-*b')
xlabel('radius')
ylabel('circumference')
grid on
title('Radius vs Circumference')

subplot(212)
plot(r,A,'-.r')
xlabel('radius')
ylabel('area')
grid on
title('Radius vs Area')

%-----------------------

%Part 4b

clear all

data=1.5*randn(10, 8);

lim1=min(data);
stdev=std(data);
avrg=mean(data);
lim2=max(data);

figure(2)
subplot(221)
plot(lim1,'r+')
title('minimum stats')
ylim([-5 5])
grid on

subplot(222)
plot(stdev,'r+')
title('std stats')
ylim([-5 5])
grid on
```

```
subplot(223)
plot(avrg, 'r+')
title('mean stats')
ylim([-5 5])
grid on

subplot(224)
plot(lim2, 'r+')
title('max stats')
ylim([-5 5])
grid on

data=1.5*randn(10, 8);

least=min(data);
stdev=std(data);
avrg=mean(data);
most=max(data);

figure(3)
subplot(221)
hold on
plot(least, 'b+')

subplot(222)
hold on
plot(stdev,'b+')

subplot(223)
hold on
plot(avrg, 'b+')

subplot(224)
hold on
plot(most, 'b+')


data=1.5*randn(10, 8);

lim1=min(data);
stdev=std(data);
avrg=mean(data);
lim2=max(data);

figure(4)
subplot(221)
plot(lim1, 'g+')

subplot(222)
plot(stdev,'g+')

subplot(223)
plot(avrg, 'g+')

subplot(224)
plot(lim2, 'g+')
```

```
data=1.5*randn(10, 8);

lim1=min(data);
stdev=std(data);
avrg=mean(data);
lim2=max(data);

figure(5)
subplot(221)
plot(lim1, 'c+')

subplot(222)
plot(stdev,'c+')

subplot(223)
plot(avrg, 'c+')

subplot(224)
plot(lim2, 'c+')


data=1.5*randn(10, 8);

lim1=min(data);
stdev=std(data);
avrg=mean(data);
lim2=max(data);

figure(6)
subplot(221)
plot(lim1, 'k+')

subplot(222)
plot(stdev,'k+')

subplot(223)
plot(avrg, 'k+')

subplot(224)
plot(lim2, 'k+')

%End


%Assignment 2

clear all
clf

load monterey.dat
whos
year=monterey(:,1);
rain=monterey(:,2:end);
dates=datenum(0,1:12,1);

plot(dates, rain(1,:), 'b')
hold on
```

```
plot(dates, rain(8,:), 'b')
dateyick('x',3)
xlabel('month of year')
ylabel('rainfall (mm)')
title ('Monterey rainfall, 1969; 1976')
legend('1969','1976')

rainearly=mean(rain(1:6,:));
rainlate=mean(rain(7:end,:));

figure(2)
plot(dates, rainearly, 'r', dates, rainlate, 'b')
datetick('x', 3)
legend('1969-74', '1975-79')
xlabel('month of year')
ylabel('rainfall(mm)')
title('monterey rainfall, means')

meanrain= mean(rain);
totalrainbyseason=sum(reshape(meanrain,3,4));

figure(3)
clf

bar(totalrainbyseason)
xlabel('season')
ylabel('total rainfall(mm)')
title(sprintf('monterey rainfall by season, total=%.0f mm', sum(meanrain)))

rainbyyear=sum(rain,2);
[orderedrain,ind]=sort(rainbyyear);
disp('year total rain(mm)')
[year(ind) orderedrain];

%end


%Assignment 3

%Part 1

data=1.5*randn(10,8,5);
means=mean(data);
maxs=max(data);
mins=min(data);
stdevs=std(data);

axlims=[0 8 -5 5];
subplot(2,2,1)
plot(squeeze(means),'+')
title('Mean'); axis(axlims); grid on
subplot(2,2,2)
plot(squeeze(maxs),'+')
title('Maximum'); axis(axlims); grid on
subplot(2,2,3)
plot(squeeze(mins),'+')
title('Minimum'); axis(axlims); grid on
subplot(2,2,4)
plot(squeeze(stdevs),'+')
```

```
title('Standard Deviation'); axis(axlims); grid on

%Part 2 & 3

x=linspace(0,20,100);
amps=[0.1 0.5 1 2]';
Cs=[2 4 6 8]';
sigmas=[0.5 1 2 3]';
beta=[amps Cs sigmas];
y=multgauss(x,beta);

figure(1)
plot(x,y)
xlabel('x');ylabel('y');title('sum of 4 gaussians')

function [ yout ] = multgauss( x,beta )

yout=zeros(size(x));

if size(beta,2)~=3
    Disp('Input matrix has incorrect number of columns.')
    return
else
    for i=1:size(beta,1)
        yout=yout+beta(i,1)*gaussmf(x,[beta(i,3) beta(i,2)]);
    end
end
end

%Part 4

data=randn(10000,10);
tic

runsum=zeros(10,1);
for i=1:size(data,1)
    for j=1:size(data,2)
        runsum(j)=runsum(j)+data(i,j);
    end
end
meany=runsum/size(data,1);

runsum=zeros(10,1);
for i=1:size(data,1)
    for j=1:size(data,2)
        runsum(j)=runsum(j)+(data(i,j)-meany(j))^2;
    end
end
vary=runsum/(size(data,1)-1);

for j=1:size(data,2)
    stdevy(j)=sqrt(vary(j));
end
toc

tic
meany2=mean(data);
vary2=var(data);
stdevy2=std(data);
```

```
toc

%Part 5

clear all
clc
data=randn(10000,10);
tic

counter=zeros(10,1);
runsum=zeros(10,1);
for i=1:size(data,1)
    for j=1:size(data,2)
        if data(i,j)>0.5
            runsum(j)=runsum(j)+data(i,j);
            counter(j)=counter(j)+1;
        end
    end
end
for j=1:size(data,2)
    meany(j)=runsum(j)/(counter(j));
end

toc

tic
for j=1:size(data,2)
meany2(j)=mean(data(data(:,j)>0.5,j));
end

toc

%end


%Assignment 4

clear all
close all
clc

month=11;
year=2005;
payrate=[5 7.5 15];
endday=eomday(year,month);
timesheet = [datenum(year,month,1:endday)' ceil(16*rand(endday,3))];
dayofweek = weekday(timesheet(:,1));
weekday = find((dayofweek~=7)|(dayofweek~=1));
weekend=find((dayofweek==7)| (dayofweek==1));
pay=sum(timesheet(weekday,2:4)).*payrate +
sum(timesheet(weekday,2:4)).*payrate*1.5;

%using switch,case statements and loop

pay2=zeros(1,3);
for j=1:endday
    switch dayofweek(j)
        case {1, 7}
            pay2=pay2+timesheet(j,2:4).*payrate*1.5;
```

```
        case{2,3,4,5,6,}
              pay2=pay2+timesheet(j,2:4).*payrate;
    end
end
pay-pay2

clear
number=23;
numbercases=10000;
birthday=round((365*rand(number,numbercases)));
birthdaysorted=sort(birthday);
duplicate=sum(dif(birthdaysorted)<1);
percentdup=sum(duplicates>=1)/numbercases;

clear
for number=10:50
    numbercases=10000;
    birthday=round((365*rand(number,numbercases)));
    birthdaysorted=sum(dif(birthdaysorted)<1);
    percentduplicate(number)=sum(duplicates>=1)/numbercases;
end

figure(1);clf
plot(percentdup*100); grid on
xlabel('number');
ylabel('birthday duplication %')
numbercrit50=find(percentdup>=0.50,1);
numbercrit95=find(percentdup>=0.95,1);

%end


%Assignment 6

clear all
close all
clc

home
data=zeros(229,407,12);
variation=dir('*.ASC');
num_names=zeros(12,1);

for n=1:length(variation)
    [z,R]=arcgridread(variation(n).name);
    names=variation(n).name;
    num_names(n,:)= str2num(names(1,16:1:17));
    data(:,:,n)=z;
end

month_num=datenum(num2str(num_names),'mm');
month_str= datestr(month_num,'mmm');
annual=sum(data,3);
figure(1)
hold on

mapshow(annual,R,'displaytype', 'testurmap')
mapshow(annual,R,'displaytype','contour','linecolor','black','levelstep',10
00)
```

```
colorbar=cb;
cb.label.string='total annual precipitation(mm)';
cbaxis([300,3000])
set9cb,'ylim';[0 1000];
xlabel('longitutde')
ylabel('latitude')
title('total annual orefgon precipitation')
writer0bj=videowriter('monthly_precip.avil');
writer0bj.framrate=0.5;
open(writer0bj);

number=12;
for j=1:number
    figure(2)
    hold off
    mapshow(data(:,:,n),r,'displaytype','texturmap')
    hold on

mapshow(data(:,:,n),r,'displaytype','contour','linecolor','black','levelste
p',100)
    colorbar=cb;
    cb.label.string='total annual precipitation(mm)';
    cbaxis([0,350])
    xlabel('longitutde')
    ylabel('latitude')
    title(['total annual orefgon precipitation in ' month_str(n,:)])
    frame=getframe(gcf);
    writevideo(writer0bj,frame);
end

close(writer0bj);

%end


%Assignment 7

clear all
close all
clc

filename='fr3_crest_.dat';
filedata=importdata(filename,3);
v=filedata.data(:,1);
y=filedata.data(:,2);

nu=0.8e-2;
k=0.4;
b=5;

wake=@(c,y) c(1)*[(1/k)*log(y*c(1)/nu)+b+2*(c(2)/k)*(3*(y/c(3)).^2-
2*(y/c(3)).^3)];
c0=[1 1 1];
disp( 'best fit for v*, wake parameter, and bounday layer thickness;')

figure(1)
plot(umodel,y,'r0')
xlabel('u (cm/s)');
ylabel('y(cm)');
```

```
legend('data','model')

%end
```

Appendix E

TOASTMASTERS
INTERNATIONAL
TOASTMASTERS
INTERNATIONAL
WHERE LEADERS ARE MADE
SPEECHCRAFT
CERTIFICATE OF
PARTICIPATION
Presented to
Sara Sultan
MIME Speaks Toastmasters Club #5249117
Oregon State University, Corvallis, Oregon, USA
November 16, 2016
Date
Sage M. Kittelman
Presenter